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**Smith et al.**

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(54) **SYSTEM AND METHOD FOR COOLING TURBINE BLADES**

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|                   |         |                      |            |
|-------------------|---------|----------------------|------------|
| 6,325,593 B1      | 12/2001 | Darkins, Jr. et al.  |            |
| 7,021,893 B2      | 4/2006  | Mongillo, Jr. et al. |            |
| 7,387,492 B2      | 6/2008  | Pang et al.          |            |
| 7,549,844 B2 *    | 6/2009  | Liang                | 416/97 R   |
| 7,762,775 B1      | 7/2010  | Liang                |            |
| 7,780,414 B1      | 8/2010  | Liang                |            |
| 7,862,299 B1 *    | 1/2011  | Liang                | 416/97 R   |
| 8,096,770 B2 *    | 1/2012  | Liang                | 416/97 R   |
| 2005/0276697 A1   | 12/2005 | McGrath et al.       |            |
| 2006/0222494 A1 * | 10/2006 | Liang                | 416/97 R   |
| 2006/0222496 A1   | 10/2006 | Lee et al.           |            |
| 2008/0031738 A1   | 2/2008  | Lee                  |            |
| 2011/0085915 A1   | 4/2011  | Krueckels et al.     |            |
| 2013/0043009 A1 * | 2/2013  | Bunker et al.        | 165/104.34 |

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**FOREIGN PATENT DOCUMENTS**

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|    |            |        |
|----|------------|--------|
| EP | 1126135 A2 | 8/2001 |
| EP | 1698757 A2 | 9/2006 |

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US 2013/0177446 A1 Jul. 11, 2013

**OTHER PUBLICATIONS**

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**F01D 25/12** (2006.01)

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CPC ..... **F01D 5/187** (2013.01); **F01D 25/12** (2013.01); **F05D 2260/202** (2013.01); **F01D 5/186** (2013.01); **F05D 2230/21** (2013.01); **F05D 2250/323** (2013.01); **F05D 2250/131** (2013.01); **F05D 2240/304** (2013.01); **Y02T 50/673** (2013.01); **Y02T 50/676** (2013.01)

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(58) **Field of Classification Search**

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USPC ..... 416/97 R; 415/115  
See application file for complete search history.

(57)

**ABSTRACT**

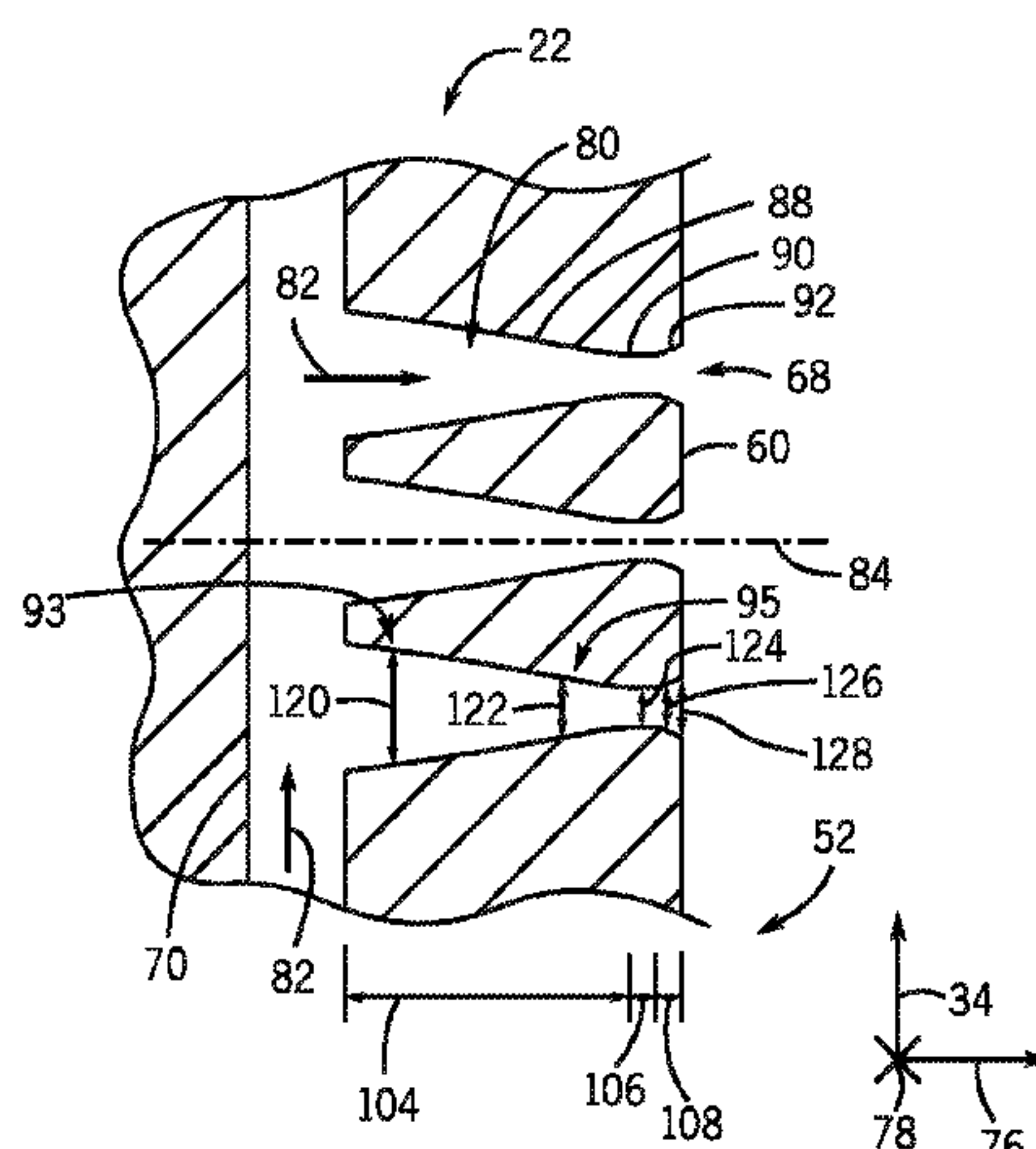
A system includes a turbine blade, which includes at least one cooling slot configured to convey a coolant in a flow direction from an interior to an exterior of the turbine blade. The cooling slot includes an entrance coupled to the interior and a converging section downstream from the entrance. The converging section includes a first cross-sectional area that decreases in the flow direction. The cooling slot also includes an exit disposed along a trailing edge of the turbine blade.

(56) **References Cited**

**U.S. PATENT DOCUMENTS**

|               |         |                  |            |
|---------------|---------|------------------|------------|
| 5,243,759 A * | 9/1993  | Brown et al.     | 29/889.721 |
| 5,246,341 A * | 9/1993  | Hall et al.      | 416/97 R   |
| 6,129,515 A   | 10/2000 | Soechting et al. |            |

**23 Claims, 3 Drawing Sheets**



(56)

References Cited

OTHER PUBLICATIONS

FOREIGN PATENT DOCUMENTS

|    |         |    |         |
|----|---------|----|---------|
| EP | 1793083 | A2 | 6/2007  |
| EP | 2267276 | A2 | 12/2010 |
| EP | 2335845 | A1 | 6/2011  |

Office Action issued in Chinese Application No. 201310001201.9,  
mailed Apr. 23, 2015, pp. 1-8.

\* cited by examiner

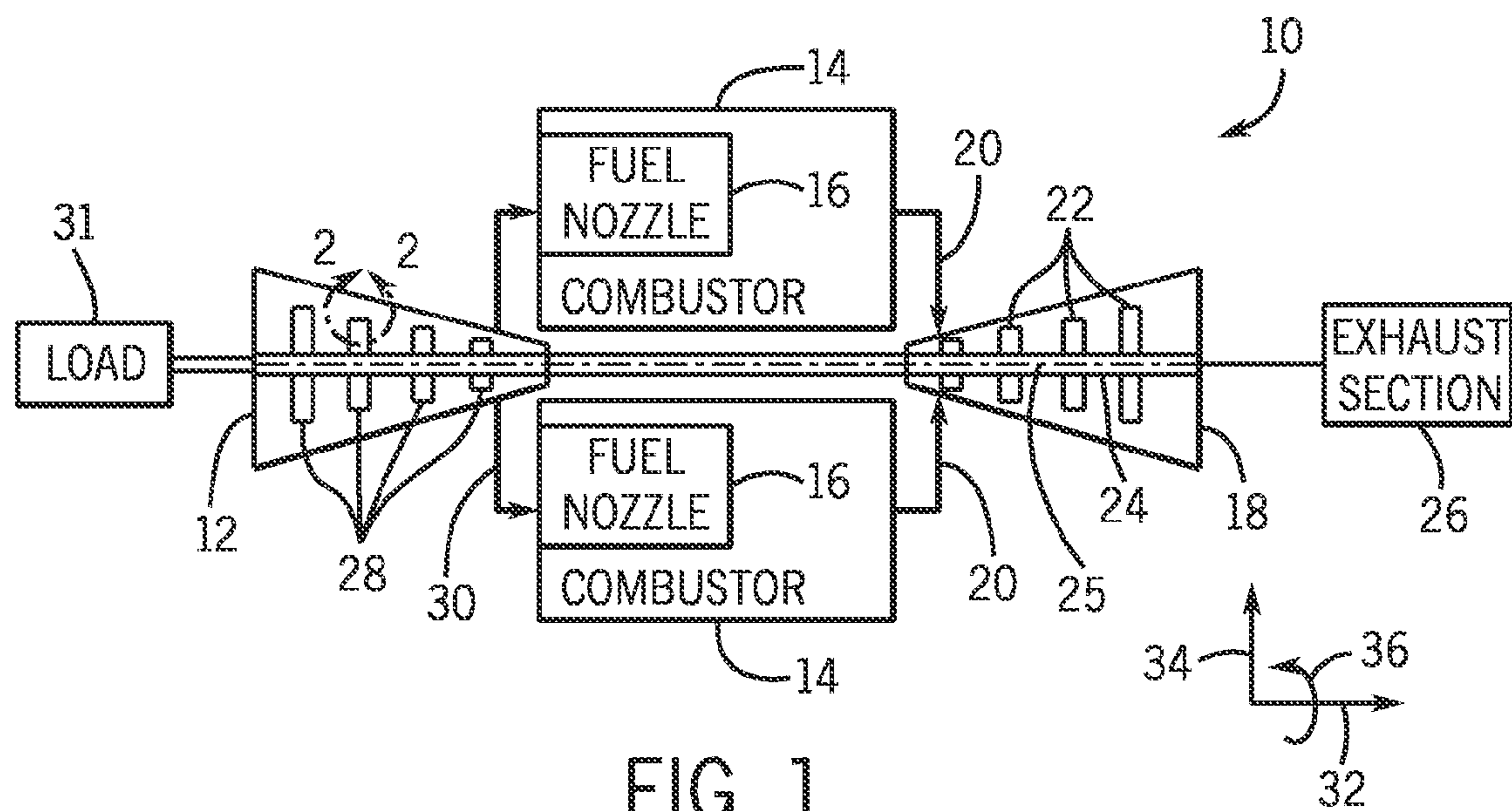


FIG. 1

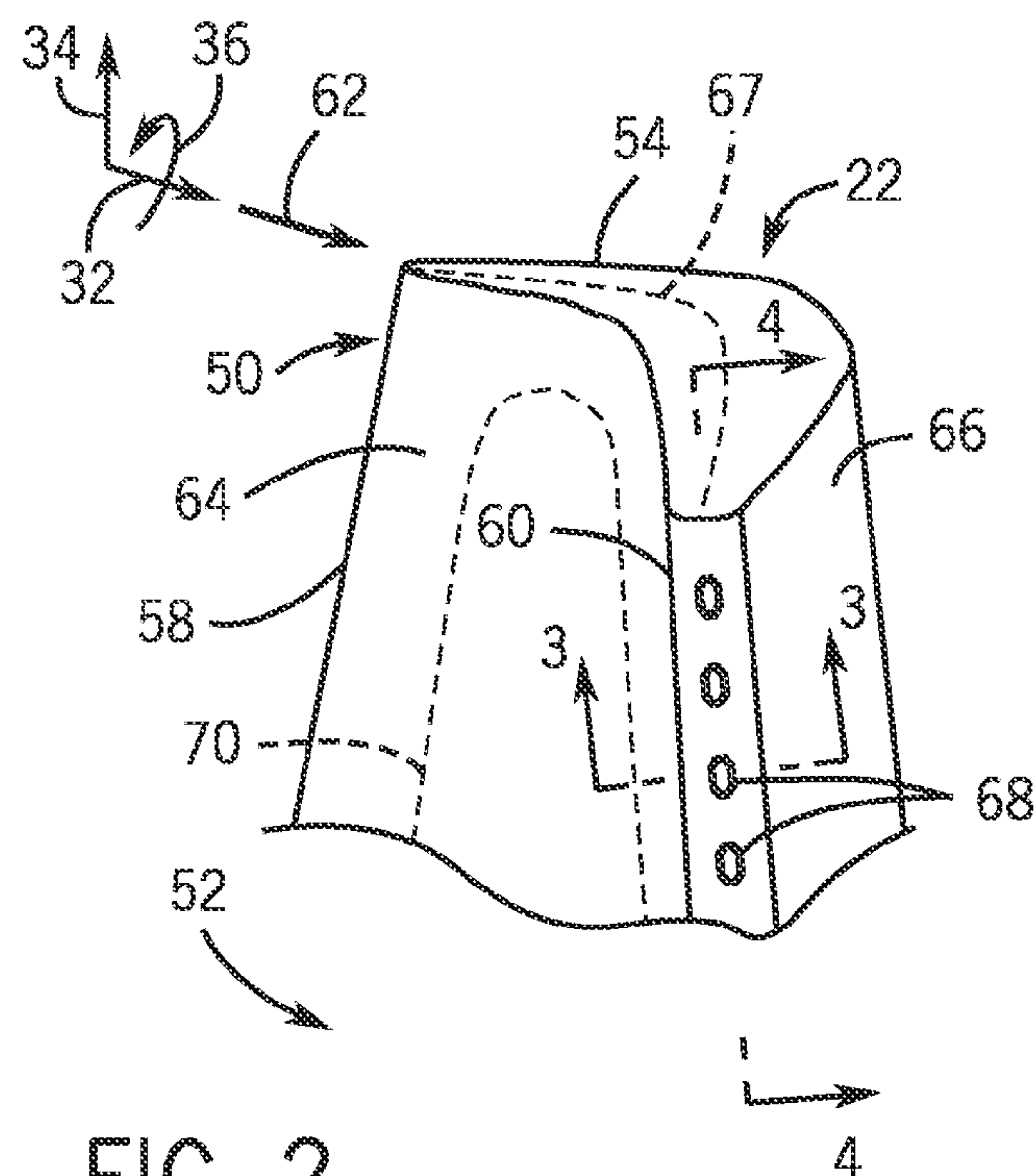
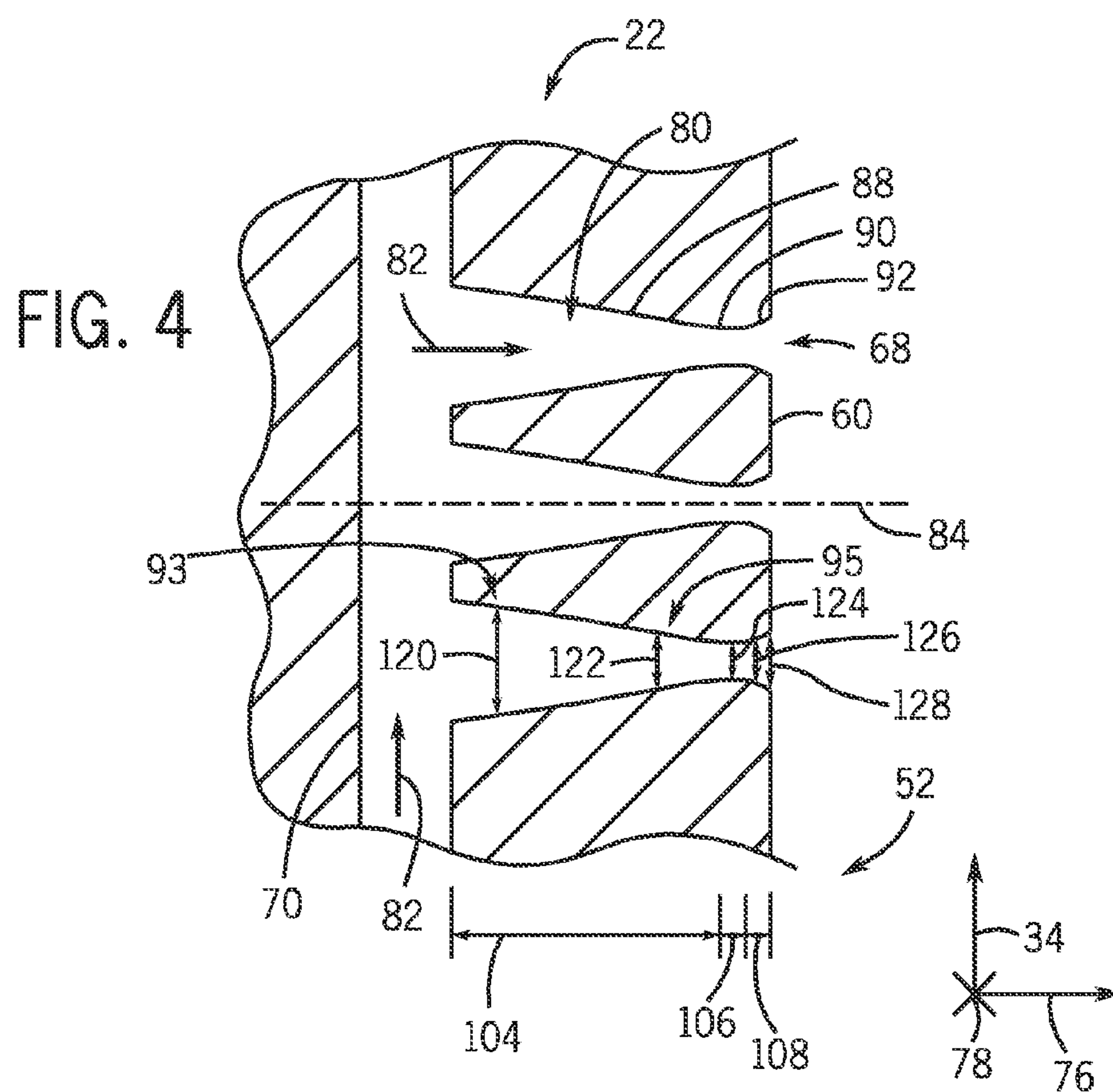
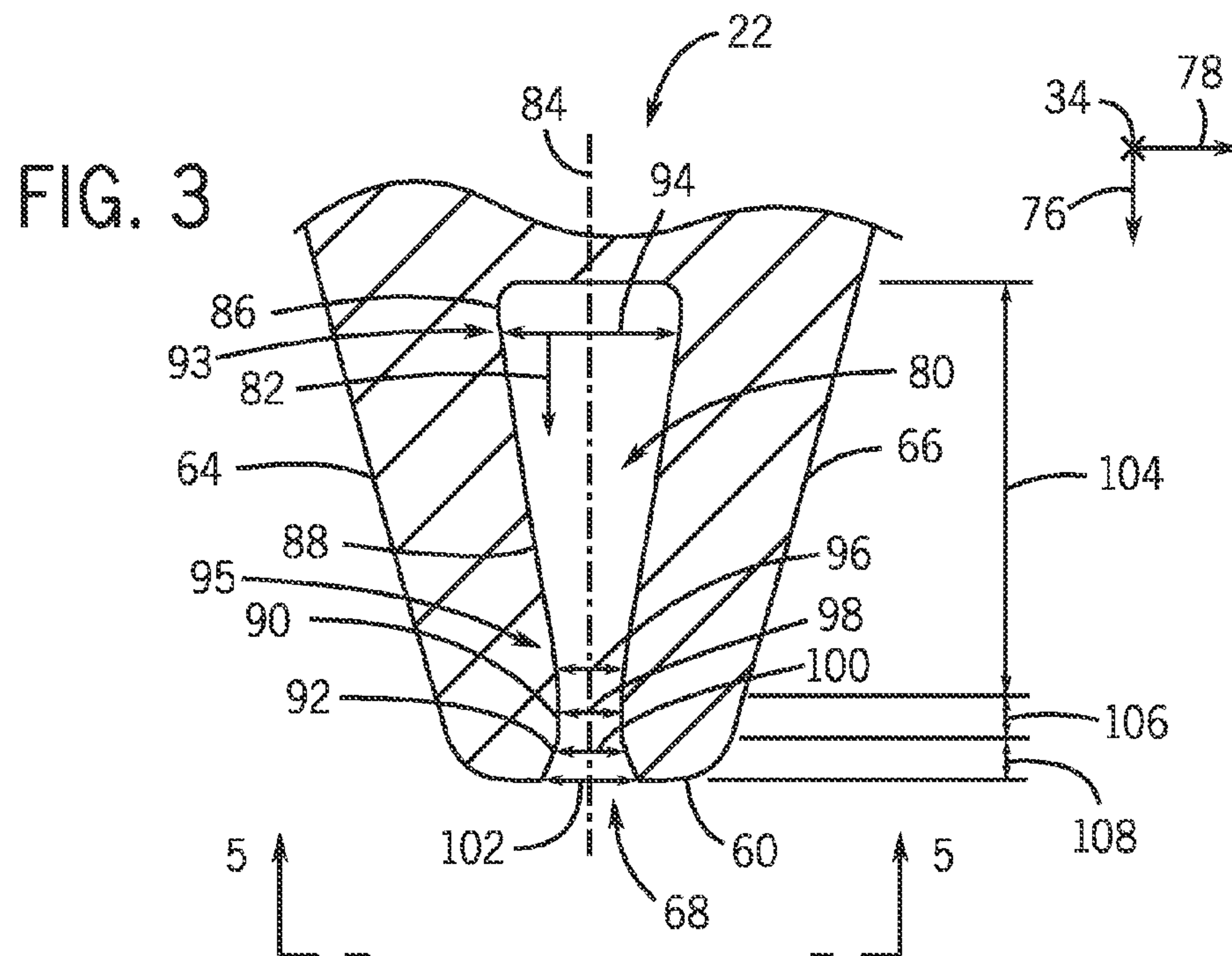


FIG. 2





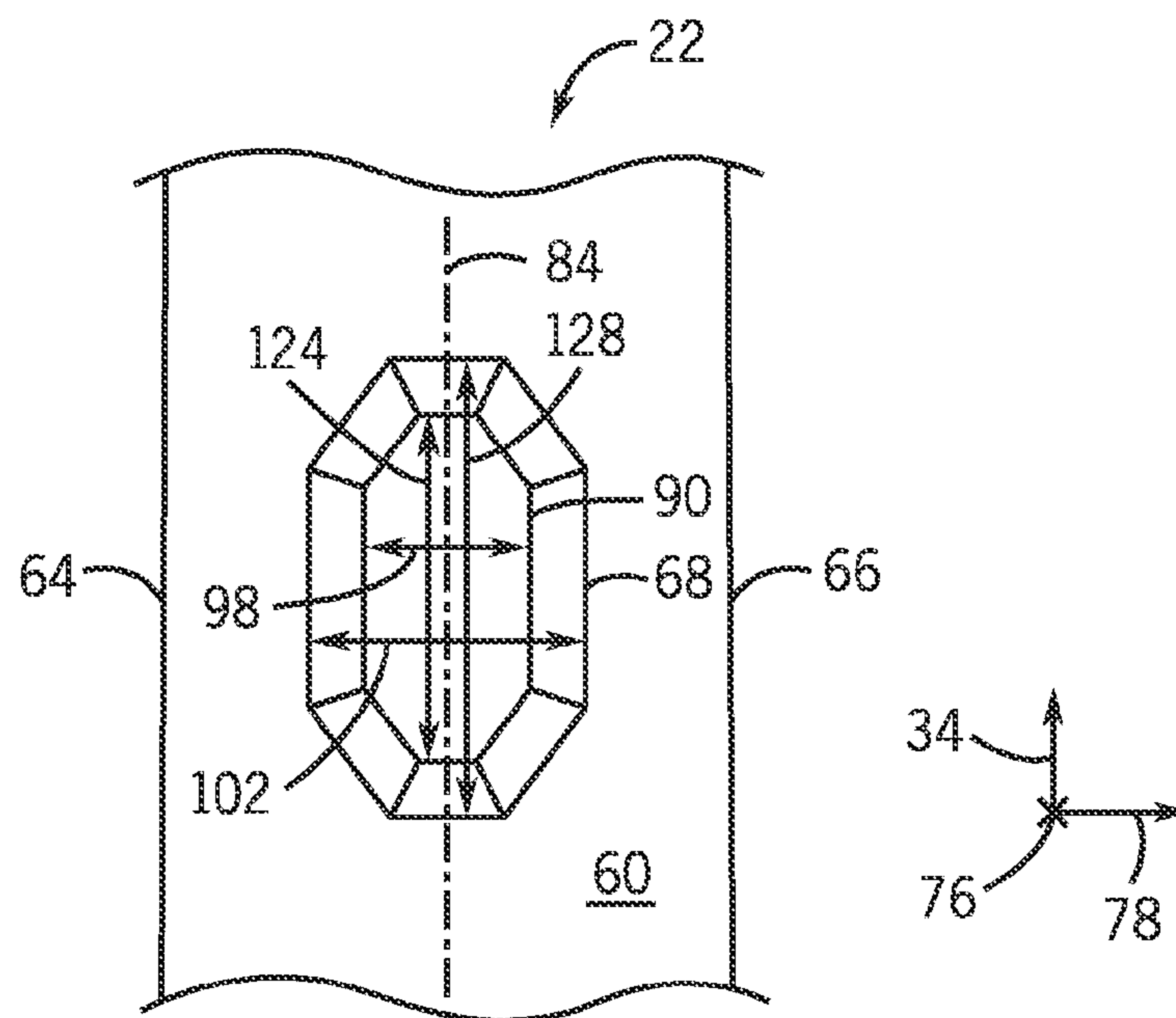


FIG. 5

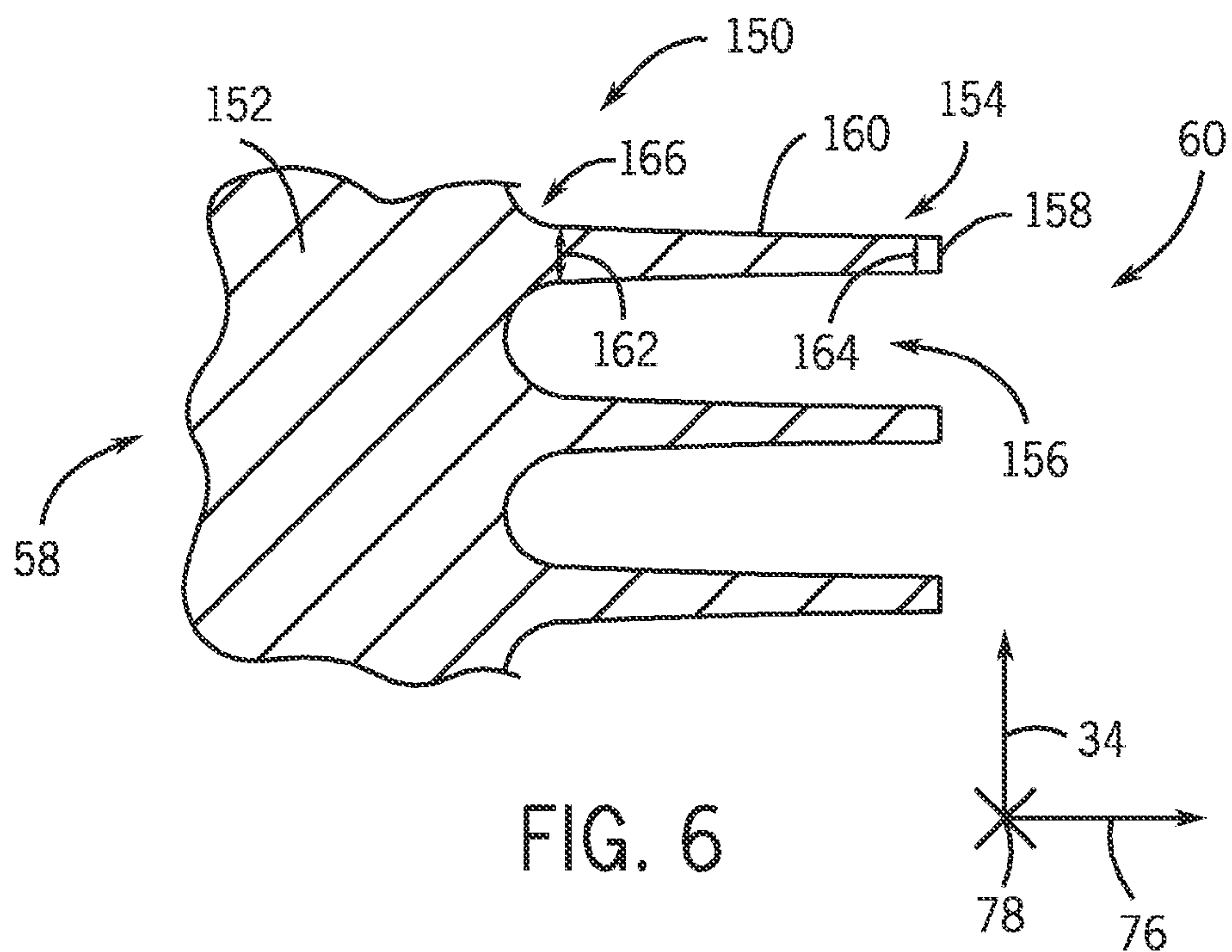


FIG. 6

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**SYSTEM AND METHOD FOR COOLING  
TURBINE BLADES****BACKGROUND OF THE INVENTION**

The subject matter disclosed herein relates to turbomachinery, and more specifically, to cooling turbine blades.

In general, gas turbine engines combust a mixture of compressed air and fuel to produce hot combustion gases. The combustion gases may flow through one or more turbine stages to generate power for a load and/or compressor. Each turbine stage includes a plurality of turbine blades, which are driven to rotate by the combustion gases. A variety of cooling techniques may be used to cool these turbine blades. Unfortunately, existing cooling techniques may not adequately cool leading or trailing edges of the blades. Furthermore, existing cooling techniques may cause casting problems in the turbine blades.

**BRIEF DESCRIPTION OF THE INVENTION**

Certain embodiments commensurate in scope with the originally claimed invention are summarized below. These embodiments are not intended to limit the scope of the claimed invention, but rather these embodiments are intended only to provide a brief summary of possible forms of the invention. Indeed, the invention may encompass a variety of forms that may be similar to or different from the embodiments set forth below.

In a first embodiment, a system includes a turbine blade, which includes at least one cooling slot configured to convey a coolant in a flow direction from an interior to an exterior of the turbine blade. The cooling slot includes an entrance coupled to the interior and a converging section downstream from the entrance. The converging section includes a first cross-sectional area that decreases in the flow direction. The cooling slot also includes an exit disposed along a trailing edge of the turbine blade.

In a second embodiment, a system includes a rotary blade. The rotary blade includes a leading edge, a trailing edge, a pressure sidewall, a suction sidewall, a cooling cavity disposed between the pressure sidewall and the suction sidewall, and a plurality of cooling slots coupled to cooling cavity. The plurality of cooling slots is configured to pass a coolant in a flow direction through the trailing edge. Each of the plurality of cooling slots includes a converging section, a metering section coupled to the converging section, and an exit disposed along the trailing edge. The converging section includes a first cross-sectional area that decreases in the flow direction. The metering section includes a second cross-sectional area that is substantially constant in the flow direction.

In a third embodiment, a method includes forming a ceramic turbine blade core, inserting the core into a die, and casting a turbine blade between the core and the die with a pressure sidewall and a suction sidewall coupled together at a leading edge and a trailing edge. The turbine blade includes a plurality of cooling slots configured to pass a coolant in a flow direction through the trailing edge. Each of the plurality of cooling slots includes a converging section, a metering section coupled to the converging section, and an exit disposed along the trailing edge. The converging section includes a first cross-sectional area that decreases in the flow direction. The metering section includes a second cross-sectional area that is substantially constant in the flow direction.

**BRIEF DESCRIPTION OF THE DRAWINGS**

These and other features, aspects, and advantages of the present invention will become better understood when the

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following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

FIG. 1 is a schematic diagram of an embodiment of a gas turbine system including a turbine having turbine blades with cooling slots;

FIG. 2 is a perspective view of an embodiment of a turbine blade having cooling slots;

FIG. 3 is a cross-sectional axial view of an embodiment of a turbine blade having cooling slots, taken along line 3-3 of FIG. 2;

FIG. 4 is a cross-sectional radial view of an embodiment of a turbine blade having cooling slots, taken along line 4-4 of FIG. 2;

FIG. 5 is a perspective view of an embodiment of a cooling slot, taken along line 5-5 of FIG. 3; and

FIG. 6 is a cross-sectional radial view of an embodiment of a core used to manufacture a turbine blade with cooling slots.

**DETAILED DESCRIPTION OF THE INVENTION**

One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

When introducing elements of various embodiments of the present invention, the articles "a," "an," "the," and "said" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements.

As discussed below, certain embodiments of the present disclosure provide a turbomachine that includes turbomachine blades (e.g., rotary blades or airfoils) with enhanced aerodynamic performance, improved durability, and/or improved longevity. For example, the turbomachine may be a turbine, such as a gas turbine or a steam turbine, having turbine blades. In other embodiments, the turbomachine may be a compressor or other turbomachine. In one embodiment, a turbine blade may include a cooling slot configured to convey a coolant. For example, the coolant may flow through the turbine blade to provide convective cooling and/or film cooling of surfaces of the turbine blade. The cooling slot may include an entrance disposed in the turbine blade, a converging section coupled to the entrance, a metering section coupled to the converging section, and an exit disposed in a trailing edge of the turbine blade. In certain embodiments, the converging section may include a first cross-sectional area, which decreases from an upstream side to a downstream side of the cooling slot. In other words, the converging section narrows from the upstream side to the downstream side of the cooling slot. The metering section may include a second cross-sectional area, which is constant from the upstream side to the downstream side of the cooling slot.

The narrowing of the converging section may cause an increase in a velocity of the coolant flowing through the



cooling slot. This increase in coolant velocity may increase the heat transfer near the downstream side of the cooling slot, thereby reducing temperatures near the downstream end of the trailing edge of the turbine blade and increasing the longevity of the turbine blade. In further embodiments, a method may include forming a substantially solid ceramic airfoil core, inserting the core into a die, and casting the airfoil with a pressure sidewall and a suction sidewall coupled together at a leading edge and a trailing edge. The airfoil may include a plurality of cooling slots extending from the trailing edge of the airfoil. In addition, each of the plurality of cooling slots may include a converging section, a metering section coupled to the converging section, and an exit disposed in the trailing edge. The first cross-sectional area of the converging section may decrease from the upstream side to the downstream side of the cooling slot, and the second cross-sectional area of the metering section may be constant from the upstream side to the downstream side of the cooling slot. The converging shape of the cooling slot of the casting may increase the strength of the casting, thereby decreasing a frequency of casting failures. In this manner, the durability and/or longevity of the turbine blade may also be improved.

Turning now to the drawings, FIG. 1 illustrates a block diagram of an embodiment of a gas turbine system 10 having turbine blades 22 with cooling slots. The system 10 includes a compressor 12, combustors 14 having fuel nozzles 16, and a turbine 18. The fuel nozzles 16 route a liquid fuel and/or gas fuel, such as natural gas or syngas, into the combustors 14. The combustors 14 ignite and combust a fuel-air mixture, and then pass hot pressurized combustion gases 20 (e.g., exhaust) into the turbine 18. Turbine blades 22 are coupled to a rotor 24, which is also coupled to several other components throughout the turbine system 10, as illustrated. As the combustion gases 20 pass through the turbine blades 22 in the turbine 18, the turbine 18 is driven into rotation, which causes the rotor 24 to rotate along a rotational axis 25. Eventually, the combustion gases 20 exit the turbine 18 via an exhaust outlet 26.

In the illustrated embodiment, the compressor 12 includes compressor blades 28. The blades 28 within the compressor 12 are coupled to the rotor 24, and rotate as the rotor 24 is driven into rotation by the turbine 18, as discussed above. As the blades 28 rotate within the compressor 12, the blades 28 compress air from an air intake into pressurized air 30, which may be routed to the combustors 14, the fuel nozzles 16, and other portions of the gas turbine system 10. The fuel nozzles 16 may then mix the pressurized air and fuel to produce a suitable fuel-air mixture, which combusts in the combustors 14 to generate the combustion gases 20 to drive the turbine 18. Further, the rotor 24 may be coupled to a load 31, which may be powered via rotation of the rotor 24. By way of example, the load 31 may be any suitable device that may generate power via the rotational output of the turbine system 10, such as a power generation plant or an external mechanical load. For instance, the load 31 may include an electrical generator, a propeller of an airplane, and so forth. In the following discussion, reference may be made to various directions, such as an axial direction or axis 32, a radial direction or axis 34, and a circumferential direction or axis 36 of the turbine 18.

FIG. 2 is a perspective view of an embodiment of the turbine blade 22. In the illustrated embodiment, the turbine blade 22 includes a blade tip 50 and a blade root 52. The blade root 52 of the turbine blade 22 may be coupled to the rotor 24 of turbine 18. Additionally, the turbine blade 22 may include a blade tip surface 54. The turbine blade 22 also includes a leading edge 58 and a trailing edge 60. As shown in FIG. 2, the leading edge 58 and the trailing edge 60 extend generally

radially 34 from the blade tip surface 54 toward the blade root 52. In addition, gases 62 may flow axially 32 toward the leading edge 58 of the turbine blade 22. The turbine blade 22 also includes a concave pressure sidewall 64 and a convex suction sidewall 66 joined together at the leading edge 58 and the trailing edge 60. A chord line 67 shown in FIG. 2 is a reference line extending from the leading edge 58 to the trailing edge 60 that connects the approximate midpoints between the pressure sidewall 64 and the suction sidewall 66. The turbine blade 22 includes a plurality of cooling slot exits 68 disposed along the trailing edge 60. The plurality of cooling slot exits 68 may be in flow communication with an internal cooling cavity 70 disposed within the turbine blade 22. For example, the cavity 70 may be disposed in an interior of the turbine blade 22. The cooling cavity 70 may flow a coolant through the cooling slot exits 68 out to an exterior of the turbine blade 22 to provide for cooling of the turbine blade. The coolant may be air or any other coolant selected to provide for cooling within the gas turbine system 10. As shown in FIG. 2, the cooling slot exits 68 are disposed entirely within (or directly along) the trailing edge 60. In other words, the cooling slot exits 68 are not disposed on the pressure sidewall 64 or the suction sidewall 66. The trailing edge 60 may receive little convective cooling from the cooling cavity 70 because of the distance between the trailing edge 60 and the cooling cavity 70. Thus, the cooling slot exits 68 may provide for direct cooling of the trailing edge 60 because of the location of the cooling slot exits 68 directly at the trailing edge 60.

FIG. 3 is a cross-sectional axial view of an embodiment of the turbine blade 22 along the line labeled 3-3 in FIG. 2. In the following discussion, reference may be made to various directions, such as a longitudinal direction or axis 76 and a transverse direction or axis 78 of the trailing edge 60 of the turbine blade 22. In the illustrated embodiment, a cooling slot 80 may be disposed within the turbine blade 22. Coolant may flow in the direction of arrow 82 toward the trailing edge 60. In addition, the cooling slot 80 may be symmetrical about a midline 84 of the trailing edge 60. The midline 84 may be generally aligned with the longitudinal axis 76 and/or the chord line 67. As shown in FIG. 3, the cooling slot 80 may be coupled to the cooling cavity 70 disposed within the turbine blade 22. As discussed above, the cooling cavity 70, or entrance, may carry the coolant to each of the plurality of cooling slots 80 disposed within the turbine blade 22. Specifically, the cavity 70 may be coupled to the interior of the turbine blade 22. Each of the cooling slots 80 may include several sections. Specifically, a converging section (or contracting section) 88 may be downstream from and coupled to the cooling cavity 70. In other words, as the coolant flows in the direction of arrow 82 (i.e., the flow direction) through the converging section 88, the cooling slot 80 converges or contracts. In addition, a metering section 90 may be downstream from and coupled to the converging section 88. Finally, an expanding section (or diverging section) 92 may be coupled to the metering section 90 and the cooling slot exit 68 of the cooling slot 80. As the coolant flows in the direction of arrow 82 through the diverging section 92, the cooling slot 80 expands or diverges. In certain embodiments, the expanding section 92 may be omitted.

In the illustrated embodiment, the converging section 88 includes a first cross-sectional area that decreases from an upstream side 93 to a downstream side 95 of the cooling slot 80. In other words, the first cross-sectional area decreases in the flow direction 82. For example, an upstream width 94 may be greater than a downstream width 96 of the converging section 88. In other words, the converging section 88 narrows



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from the upstream side **93** to the downstream side **95**. Thus, a velocity of the coolant flowing in the direction **82** may increase through the converging section **88**. In the illustrated embodiment, the metering section **90** may be characterized by a metering section width **98**, which may be approximately the same or less than the downstream width **96** of the converging section **88**. As shown in FIG. 3, the metering section width **98**, and accordingly a second cross-sectional area of the metering section **98**, may be constant. In other words, the metering section width **98**, and accordingly the second cross-sectional area, is substantially constant in the flow direction **82**. The metering section **90** may be used to adjust a flow rate of the coolant flowing through the cooling slot **80**. For example, a metering section **90** with a smaller metering section width **98** may reduce the flow rate of the coolant. Similarly, a larger metering section width **98** may enable a higher coolant flow rate through the cooling slot **80**. The expanding section **92** may be defined by an expanding section width **100**, which may be greater than the metering section width **98**. The expanding section **92** includes a third cross-sectional area that increases in the flow direction **82**. In addition, the expanding section **92** may provide for a wider or more distributed flow of the coolant along the trailing edge **60**. The cooling slot exit **68** may be defined by a cooling slot opening width **102**, which may be greater than the expanding section width **100**.

As shown in FIG. 3, the converging section **88** may be defined by a converging section length **104**, the metering section **90** may be defined by a metering section length **106**, and the expanding section **92** may be defined by an expanding section length **108**. In the illustrated embodiment, the converging section length **104** is greater than the metering section length **106**. In certain embodiments, a ratio of the converging section length **104** to the metering section length **106** may be between approximately 1.1:1 to 10:1, 2:1 to 8:1, or 4:1 to 6:1. A longer converging section length **104** may enable the coolant velocity to gradually increase through the converging section **88** to provide for improved heat transfer moving toward the trailing edge **60**. The metering section length **106** may be used together with the metering section width **98** to adjust a flow rate of the coolant exiting from the cooling slot **80**. The expanding section length **108** may be selected to provide for even distribution of the coolant across the trailing edge **60**. In addition, although the cooling slot **80** is shown symmetrical about the midline **84**, in other embodiments, the cooling slot **80** may not be symmetrical about the midline **84**. For example, the cooling slot **80** may be oriented to direct the coolant more toward the pressure sidewall **64** or more toward the suction sidewall **66**. In other words, the cooling slots **80** may not be aligned exactly with the longitudinal axis **76** in certain embodiments.

FIG. 4 is a cross-sectional radial view of an embodiment of the turbine blade **22** along the line labeled 4-4 in FIG. 2. In the illustrated embodiment, the cooling cavity **70** connects several of the cooling slots **80**, enabling the coolant to flow in the direction **82** through each of the cooling slots **80**. As shown in FIG. 4, the converging section **88** includes a cross-sectional area that decreases from the upstream side **93** to the downstream side **95**. Thus, the converging section **88** narrows in two dimensions, namely the transverse direction **78** and the radial direction **34**. Thus, the converging section **88** may include an upstream height **120** and a downstream height **122**. As shown in FIG. 4, the upstream height **120** is greater than the downstream height **122**. In other words, the converging section **88** narrows from the upstream side **93** to the downstream side **95** in the radial direction **34**. In certain embodiments, the upstream height **120** may be approximately the same as the upstream width **94** and the downstream height

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**122** may be approximately the same as the downstream width **96**. In other words, the converging section **88** may narrow the same amount in both the transverse direction **78** and the radial direction **34**. Thus, the converging section **88** may be a conical passage. In other embodiments, the upstream height **120** may be different from the upstream width **94** and/or the downstream height **122** may be different from the downstream width **96**. In other words, the converging section **88** may narrow to a different degree in the circumferential direction **36** than in the radial direction **34**.

As shown in FIG. 4, the metering section **90** includes a metering section height **124**, which may be the same or different from the metering section width **98**. In addition, the expanding section **92** may include an expanding section height **126**, which may be the same or different from the expanding section width **100**. Finally, the exit **68** may include an opening height **128**, which may be the same or different from the opening width **102**. In certain embodiments, the converging section **88** may converge only in one dimension. In other words, the converging section **88** may converge only in the transverse direction **78** or only in the radial direction **34**. However, as discussed in detail below, the casting strength may be increased when the converging section **88** converges in both the transverse direction **78** and the radial direction **34**, or generally in two dimensions. Further, although the cooling slot **80** is shown symmetrical about the midline **84** (e.g., a conical cooling slot **80**), in other embodiments, the cooling slot **80** may not be symmetrical about the midline **84**. For example, the cooling slot **80** may be oriented to direct the coolant more toward the blade tip surface **54** (e.g., angled up) or more toward the blade root **52** (e.g., angled down). In other words, the cooling slots **80** may not be aligned exactly with the longitudinal axis **76** in certain embodiments.

FIG. 5 is a perspective view of an embodiment of the turbine blade **22** showing the exit **68** of the cooling slot **80**. As shown in FIG. 5, the exit **68** is disposed along the midline **84** of the trailing edge **60**, which may be generally aligned with the radial axis **34**. In addition, the outlines of both the metering section **90** and the exit **68** may be visible from the perspective view of the turbine blade **22** shown in FIG. 5. Examples of shapes of the exit **68** include, but are not limited to, circles, ovals, squares, rectangles, polygons, and so forth. In the illustrated embodiment, the metering section height **124** is greater than the metering section width **98**. Similarly, the opening height **128** is greater than the opening width **102**. In other embodiments, the heights **124** and **128** may be approximately the same as the widths **98** and **102**. In further embodiments, the heights **124** and **128** may be less than the widths **98** and **102**. In addition, the exit **68** of the cooling slot **80** is disposed between the pressure sidewall **64** and the suction sidewall **66**. Thus, the exit **68** does not extend onto the pressure sidewall **64** or the suction sidewall **66**. This configuration of the exit **68** may increase the amount of cooling provided to the trailing edge **60**.

FIG. 6 is a cross-sectional radial view of an embodiment of a core **150** used in the manufacture of the turbine blade **22**. In one embodiment, the turbine blades **22**, or airfoils, may be fabricated by casting the core **150**. For example, the core **150** may be fabricated by injecting a liquid, such as a liquid ceramic and graphite slurry, into a core die (not shown). The liquid may then be heated to form the solid ceramic airfoil core **150**. The airfoil core **150** may then be suspended in an airfoil die (not shown) and hot wax injected into the airfoil die to surround the ceramic airfoil core **150**. The hot wax then solidifies and forms a wax airfoil with the ceramic core **150** suspended in the airfoil. The wax airfoil with the ceramic core **150** may then be repeatedly dipped into a ceramic slurry to



form a ceramic shell outside the wax airfoil. The core **150**, wax, and shell cluster may then be heated to an elevated temperature to remove the wax to form a casting mold with the ceramic core **150** in the middle. Molten metal may then be poured into the hollow casting mold. The molten metal takes the place of the wax airfoil, and forms the metal airfoil **22** with the ceramic core **150** remaining in place. The airfoil **22** is then cooled, and the ceramic core **150** removed.

As shown in FIG. 6, a bulk portion **152** of the core **150** may correspond to the cooling cavity **70** and extensions **154** may correspond to the cooling slots **80**. Spaces **156** between the extensions **154** may correspond to the structure between the cooling slots **80** of the turbine blade **22**. Ends **158** of the extensions **154** may correspond to the narrowest end, or downstream side **95**, of the converging section **88** of the turbine blade **22**. Thus, the metering section **90** and the expanding section **92** may be formed in the turbine blade **22** by drilling or cutting through the turbine blade **22** after removing the core **150**. A converging portion **160** of the extensions **154** may correspond to the converging section **88** of the cooling slot **80** of the turbine blade **22**. An upstream height **162** may correspond to the upstream height **120** and a downstream height **164** may correspond to the downstream height **122** of the converging section **88** of the turbine blade **22**. As shown in FIG. 6, the portion of the extension **154** attached to the bulk portion **152**, i.e., an extension base **166**, is wider than the ends **158** of the extensions **154**. Thus, the extensions **154** may be less prone to cracking or breaking away from the bulk portion **152** during manufacturing of the turbine blade **22** because of the increased strength of the extension bases **166**.

As discussed above, embodiments of the turbine blades **22** include a cooling slot **80** that facilitates extending a useful life of the turbine blade **22**. Specifically, the turbine blades **22** may include a plurality of cooling slots **80** that include the entrance **70**, the converging section **88** coupled to the entrance **70**, the metering section **90** coupled to the converging section **88**, and the exit **68** disposed in the trailing edge **60** of the turbine blade **22**. The first cross-sectional area of the converging section **88** decreases from upstream side **93** to the downstream side **95** of the cooling slot **80**. The second cross-sectional area of the metering section **90** may be constant from the upstream side **93** to the downstream side **95** of the cooling slot. The cooling slots **80** facilitate enhanced cooling and flow regulation with improved manufacturing yields. As a result, the trailing edge cooling slot geometry configuration of the turbine blades **22** facilitates extending a useful life of the turbine blades **22** in a cost-effective and reliable manner. Exemplary embodiments of turbine blades **22** are described above in detail. The turbine blades **22** may be disposed on rotating surfaces of the gas turbine system **10**, such as a rotor, on stationary surfaces, such as a stator, or both the rotor and stator. The cooling slots **80** described above are not limited to use with the specific embodiments of turbine blades **22** described herein, but rather, the cooling slots **80** may be utilized independently and separately from other rotor or stator components described herein.

This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they have structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

The invention claimed is:

1. A system, comprising:

a turbine blade comprising at least one cooling slot configured to convey a coolant in a flow direction from an interior to an exterior of the turbine blade, wherein the cooling slot comprises:

an entrance coupled to the interior;

a converging section downstream from the entrance, wherein the converging section comprises a first cross-sectional area that decreases in the flow direction; and

an exit disposed along a trailing edge of the turbine blade, wherein the cooling slot comprises at least one of:

only one metering section, wherein the metering section is disposed only downstream from the converging section; or

the exit of the cooling slot is disposed along the trailing edge on a midline between a pressure sidewall and a suction sidewall, wherein the exit comprises a diverging section; or

a combination thereof.

2. The system of claim 1, comprising the only one metering section, wherein the metering section is disposed only downstream from the converging section.

3. The system of claim 2, wherein the converging section comprises a first length in the flow direction, the metering section comprises a second length in the flow direction, and the first length is greater than the second length.

4. The system of claim 2, wherein the metering section comprises a second cross-sectional area that is substantially constant in the flow direction.

5. The system of claim 1, wherein the exit is disposed along the trailing edge on the midline between the pressure sidewall and the suction sidewall, wherein the exit comprises the diverging section.

6. The system of claim 5, wherein the diverging section comprises a third cross-sectional area that increases in the flow direction.

7. The system of claim 1, wherein the converging section comprises a height and a width, wherein both the height and the width decrease in the flow direction.

8. The system of claim 7, wherein the height and the width are different from one another.

9. The system of claim 1, wherein a cross-sectional shape of the converging section comprises at least one of a circle, an oval, a square, a rectangle, or a polygon, or a combination thereof.

10. The system of claim 1, comprising a turbine having the turbine blade.

11. The system of claim 1, wherein the cooling slot is symmetrical about the midline between the pressure sidewall and the suction sidewall.

12. The system of claim 1, wherein the cooling slot comprises:

the metering section disposed only downstream from the converging section; and

the exit disposed along the trailing edge on the midline between the pressure sidewall and the suction sidewall.

13. A system, comprising:

a rotary blade, comprising:

a leading edge;

a trailing edge;

a pressure sidewall;

a suction sidewall;

a cooling cavity disposed between the pressure sidewall and the suction sidewall; and



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a plurality of cooling slots coupled to cooling cavity, wherein the plurality of cooling slots is configured to pass a coolant in a flow direction through the trailing edge, and each slot of the plurality of cooling slots comprises:

a converging section comprising a first cross-sectional area that decreases in the flow direction;

only one metering section, wherein the metering section is coupled to the converging section, wherein the metering section is disposed only downstream from the converging section, and the metering section comprises a second cross-sectional area that is substantially constant in the flow direction; and

an exit disposed along the trailing edge on a midline between the pressure sidewall and the suction sidewall, wherein the exit comprises a diverging section.

**14.** The system of claim **13**, wherein the exit is centered directly on the midline.

**15.** The system of claim **13**, wherein each converging section comprises a height and a width, wherein both the height and the width decrease in the flow direction.

**16.** The system of claim **13**, wherein each converging section comprises a first length in the flow direction, each metering section comprises a second length in the flow direction, and a ratio of the first length to the second length is greater than approximately 5:1.

**17.** The system of claim **13**, wherein the diverging section comprises a third cross-sectional area that increases in the flow direction.

**18.** The system of claim **13**, comprising a turbomachine having the rotary blade, wherein the rotary blade is disposed on a rotor.

**19.** A method, comprising:  
forming a ceramic turbine blade core;  
inserting the core into a die; and

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casting a turbine blade between the core and the die with a pressure sidewall and a suction sidewall coupled together at a leading edge and a trailing edge, wherein the turbine blade comprises a plurality of cooling slots configured to pass a coolant in a flow direction through the trailing edge, and each slot of the plurality of cooling slots comprises:

a converging section comprising a first cross-sectional area that decreases in the flow direction;

a metering section coupled to the converging section; and

an exit disposed along the trailing edge, wherein each slot of the plurality of cooling slots comprises at least one of:

only the one metering section, wherein the metering section is disposed only downstream from the converging section; or

the exit is disposed along the trailing edge on a midline between the pressure sidewall and the suction sidewall, wherein the exit comprises a diverging section; or

a combination thereof.

**20.** The method of claim **19**, wherein the exit is disposed along the trailing edge on the midline between the pressure sidewall and the suction sidewall, wherein the exit is centered on the midline.

**21.** The method of claim **19**, wherein the first cross-sectional area of the converging section decreases in at least two dimensions.

**22.** The method of claim **19**, wherein the converging section comprises a first length in the flow direction, the metering section comprises a second length in the flow direction, and the first length is greater than the second length.

**23.** The method of claim **19**, wherein the metering section is disposed between the converging section and the diverging section.

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